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STUDIES ON SOW LAMENESS AND RELATED PATHOLOGICAL FINDINGS

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ABSTRACT

Lameness of sows is a very common problem in the modern pig industry. It impairs both health and welfare of sows and production economics of farms. Lameness is a clinical sign caused by various problems associated with the locomotor system. However, the exact cause of lameness often remains undetermined and lame sows do not always get the necessary attention and treatment.

The overall aim of this thesis was to gather information and add to the scientific knowledge on sow lameness. The specific aims of the studies were to investigate pathological-anatomical findings in the locomotor system of euthanized and spontaneously dead sows, to examine the effect of oral ketoprofen in treatment of lameness, and to study the effect of lameness on behavior of the sows.

The pathological-anatomical findings in the locomotor system were examined in a descriptive study. The convenience sample consisted of 38 euthanized and 27 spontaneously dead sows from 15 Finnish farms. The majority (91%) of sows had one or more lesions in their locomotor system. The most common primary pathological-anatomical diagnosis (PAD) was inflammatory arthritis, with a prevalence of 9%. Degenerative joint disease (DJD) was diagnosed in 71% of the animals. DJD was the most frequent incidental finding, and its association with lameness remains in question. Lameness was however the most commonly reported clinical sign observed by the farmer within 30 days preceding death.

The effect of oral ketoprofen in treatment of non-infectious lameness was evaluated in a randomized, double-blinded, controlled field trial. Altogether 141 lame sows were allocated to three groups: two dose rates of oral ketoprofen (2 mg/kg and 4 mg/kg) were compared with placebo treatment over five consecutive days. Lameness was assessed using a five-grade scoring system prior to and on the last day of the treatment. Treatment of lameness was considered successful for 54% of the sows in the ketoprofen 4 mg/kg group, for 53% in the ketoprofen 2 mg/kg group and for 21% of the sows in the placebo group.

Parallel with the above-mentioned study, a randomized, double-blinded, controlled field trial was conducted to evaluate the effects of lameness and ketoprofen treatment on behavior of sows. Thirteen lame sows were allocated to treatment groups and paired with a healthy, non-lame control sows. Behavior was observed using a scan-sampling method prior to and after the treatment. Before the treatment on day 0, lame sows were observed to be more passive,

lie down more and stand and explore pen fixtures less than the healthy control sows. On day 5 of the treatment, the behavior of sows with relieved lameness did not differ from that of healthy control sows, indicating that these sows had most likely been in pain before treatment. Some behavioral differences were apparent between sows with relieved and non-relieved lameness, showing that the latter sows were still in pain. The sows with non-relieved lameness were in contact with the wall and lay down significantly more often and moved and stood less than healthy control sows on day 5 of the treatment.

In conclusion, pathological-anatomical findings in the locomotor system were very common in on-farm-dead sows. In future, more research is needed to evaluate the clinical relevance of these diagnoses and their association to lameness. Oral ketoprofen proved to be an effective treatment in alleviating the non-infectious lameness of sows. The differences in behavior between lame and healthy control sows and also between the ones with relieved and non-relieved lameness indicated that most of the lame sows were in pain and that the treatment of lameness is important from the animal welfare point of view.

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CONTENTS

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications, referred to in the text by their Roman numerals:

I Ala-Kurikka E*, Munsterhjelm C*, Bergman P, Laine T, Pekkarinen H, Peltoniemi O, Valros A, Heinonen M (*equal contribution). 2019. Pathological findings in spontaneously dead and euthanized sows – a descriptive study. Porcine Health Management. 5: 25.

II Mustonen K, Ala-Kurikka E, Orro T, Peltoniemi O, Raekallio M, Vainio O, Heinonen M. 2011. Oral ketoprofen is effective in the treatment of non-infectious lameness in sows. Veterinary Journal. 190: 55–59.

III Ala-Kurikka E, Heinonen M, Mustonen K, Peltoniemi O, Raekallio M, Vainio O, Valros A. 2017. Behavior changes associated with lameness in sows. Applied Animal Behaviour Science. 193: 15–20.

1. INTRODUCTION

There are 12 million sows in Europe. Sows are the cornerstone of pork production because they produce the piglets that are fattened for human consumption. Currently, the average lifetime of a sow is approximately three years, four parities (Engblom et al., 2007). Optimally, sows should stay in production until their sixth to tenth parity (Niemi et al., 2017), but for unplanned reasons most sows are removed from farms prematurely.

Lameness is defined as abnormal gait, most often associated with pain. In sows, lameness is a major problem. It affects a substantial number of sows: the prevalence of sow lameness has been reported to be 5–17% (Willgert et al., 2014; KilBride et al., 2009). Lameness impairs both health and welfare of sows and the profitability of pig farms. Being one of the foremost reasons for premature, unplanned removal of sows, lameness is a key factor in sow longevity (Pluym et al., 2013b).

Lameness is not a single disease, but a clinical sign with various causes (Potterton et al., 2012). However, there are very few scientific reports that address the exact causes of sow lameness. Despite the known consequences for animal welfare, productivity and longevity, the prevention and treatment of lameness continue to attract insufficient attention (Nalon & Stevenson, 2019). In general, recognizing the diagnosis behind lameness is a prerequisite for selecting the correct treatment and establishing preventive measures.

In the European Union animals kept for farming purposes are legally protected (Directive 98/58/EC). Article 3 provides that caretakers must "take all reasonable steps to ensure the welfare of animals under their care and to ensure that those animals are not caused any unnecessary pain, suffering or injury". In other words, the attempt has to minimize lameness and to treat lame animals appropriately. Lame sows should not be overlooked.

The aim of this thesis is to gather information and add to the scientific knowledge on sow lameness. New knowledge is needed to help make more reasonable decisions concerning the diagnosis and treatment of lame sows. The goal is also to explore the importance and prevention of lameness and, finally, to give stimuli for future research on sow lameness. In the following chapters, first main results about the importance, assessment, causes, treatment and behavioral effects of sow lameness from the scientific literature will be reviewed. Secondly, the aims, methodology and results of the research underlying this thesis will be presented, and thirdly, the results will be discussed in relation to those of earlier studies. Together, the literature review and results are expected to broaden the understanding of lameness in sows. The final goal is that the findings of the thesis help to improve health and longevity of sows, and contribute towards better animal welfare and more sustainable use of animal resources.

2. REVIEW OF LITERATURE

2.1 SOW LAMENESS

Lameness is defined as departure from normal gait (Anonymous, 2015). It can manifest as a decreased symmetry of limb movement, an alteration or shortening of stride, or a reduced ability or inability to bear weight (Straw et al., 1999; Maas, 2009). The severity of lameness varies greatly, total recumbency without an ability to stand up being the most extreme manifestation.

Lameness is not a single disease but rather a clinical sign associated with a range of conditions (Potterton et al., 2012). In general, lameness is the clinical sign of musculoskeletal problems. The exact reason for lameness in sows is very difficult to diagnose under farm conditions (Dewey et al., 1993; Heinonen et al., 2006). Lameness is often used as a general diagnosis in both veterinary practice and in scientific pig research. For example, most journal articles referred to in this thesis that addressed lameness of sows did so without defining the exact cause of lameness.

Pain is defined as ´An unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage' by the International Association for the Study of Pain (IASP, 1979). Pain in animals has inspired several researchers to investigate the issue, but reviewing those results is not included into the extent of this thesis. However, it is notable that lameness is most often accompanied by pain, or it is used as an indicator of locomotor pain (Ison et al., 2016).

2.1.1 IMPORTANCE

Lameness of sows is an important issue in the modern pig industry. It impacts health and welfare of sows and production economics of farms (Heinonen et al., 2013; Willgert et al., 2014). Its prevalence has been reported to be high, ranging from 5% to 17%, which underlines the significance of the condition as a major health issue in sows (Willgert et al., 2014; KilBride et al., 2009).

Animal welfare is a multidimensional concept, which comprises both physical and mental health. It includes many aspects such as physical comfort, absence of hunger and disease and possibility to perform motivated behavior (Welfare Quality, 2009). Lameness affects welfare due to physically reduced locomotion ability, pain and general discomfort (Heinonen et al., 2013). Owing to the pain, suffering and limited freedom of movement, lameness as a single factor can be recognized as a major welfare concern. In 2003, lameness was ranked as the most important measure of pig welfare assessment in a survey of experts (Whay et al., 2003). Subsequently, lameness was implemented in the Welfare Quality Assessment Protocol for Pigs (2009) as an animal-based measure. Lameness was selected as a protocol to assess the welfare criterion "Absence of injuries", which reflects one of the main principles of animal welfare, good health. In addition, citizens are concerned about animal welfare in pig production, such as physical wellbeing and health (Boogaard et al., 2011), and lameness is considered by the public to be a significant contributory factor in this regard.

Increased labor and other costs associated with treating sow lameness reduce the sow farm's production efficiency. The financial loss due to lameness has been estimated to be €37–133 per lame sow (Deen et al., 2008). More recently in a Finnish dataset, the economic burden of locomotor disorders per diseased sow was €290–330. For an average-sized herd (469 sows per herd in the 2014 dataset) this meant losses of about €11000 annually. The constant presence and high incidence make the overall costs of lameness likely greater than those of highly contagious diseases that occur only rarely (Niemi et al., 2017). Furthermore, lameness is thought to impair reproduction abilities of sows, but literature on the direct impact of lameness on reproduction does not clearly confirm this. Heinonen et al. (2006) found no difference in pregnancy rate between lame and non-lame animals. Similarly, Pluym et al. (2013b) found no significant associations between general lameness and reproductive parameters, whereas a single cause of lameness, some claw lesions, was associated with farrowing performance. Presence of skin lesions above the claw and white line lesions increased the odds of stillborn piglets and heel erosions were associated with presence of crushed piglets (Pluym et al., 2013b). However, as only a few sows in the study sample did not have any heel lesion, the association between heel lesions and crushed piglets may have been coincidental. The idea of the association between lameness and reproductive capacity is nonetheless logical. It is likely, that lame sows show less estrus behavior, which makes estrus detection more difficult, their difficulties in lying down may result in piglets being crushed and the tendency to sit more may increase the risk for getting environmental pathogens infecting the reproductive system.

2.1.2 LONGEVITY AND REMOVAL OF SOWS

Sow longevity is desirable from both economic and ethical points of view as it is a key feature in improving farm profitability and is also associated with overall animal welfare (Engblom et al., 2007). Usually, longevity refers to length of productive lifetime rather than the sow's natural lifespan (Calderón Díaz et al., 2015). The optimal lifetime of a sow is not fixed: rather it depends on sow health, litter size, piglet mortality and reproductive efficiency (Niemi et al., 2017). According to many studies, approximately 50% of sows are removed (i.e., replaced) annually (Bergman et al., 2019; Engblom et al., 2007). Sows are replaced to ensure a good level of productivity, and optimally removals should be done according to structured plan. Old age and low productivity are the most common reasons for planned removals (Heinonen et al., 1998; Lucia et al., 2000). Nevertheless, approximately 70% of sow removals are premature, unplanned and involuntary (Engblom et al., 2011). In culling records collected in China, up to 98% of the removals were reported to be unplanned (Wang et al., 2019). The average removal parity ranges from 2.3 to 4.6 (Wang et al., 2019; Boyle et al., 1998), although the optimal removal parity for a healthy sow would be at least six or seven (Niemi et al., 2017).

Lameness mainly affects farm productivity indirectly through its effect on sow longevity (Pluym et al., 2013b). Together with reproductive problems, it is the most common reason for unplanned sow removals (Engblom et al., 2007; Wang et al., 2019). Lame sows have a higher risk of being removed from the herd (Anil et al., 2009). Also, many sows reportedly culled for other reasons, such as reproductive failure, may have been culled as a primary result of lameness that occurred earlier in life (Abell et al., 2014).

A substantial proportion, about 10–15% of removed sows are euthanized or found dead (Lucia et al., 2000; Engblom et al., 2011; Knage-Rasmussen et al., 2015). Spontaneous death and euthanasia of sows are truly involuntary and unplanned removals. Euthanasia is most often committed for a biological reason, which is not within the authority of the farmer. There is obviously a biological reason for spontaneous deaths too. To some extent, the level of spontaneous deaths depends on the threshold for committing euthanasia, which is specific for each farm. In published papers, euthanasia is mainly excluded from sow mortality, which therefore includes only spontaneous deaths (Sanz et al., 2007; Sasaki & Koketsu, 2008; Welfare Quality, 2009). It is justified to separate euthanasias and spontaneous deaths, as reasons for them seem to differ. Lameness (or a locomotor problem) is a dominant factor leading to euthanasia (Kirk et al., 2005; Sanz et al., 2007; Engblom et al., 2008), but it is only very rarely a reason for spontaneous death (Kirk et al., 2005). It is certainly more accurate to separate spontaneous deaths and euthanasia, but when it is relevant, on-farm-death (OFD) (Sarjokari et al., 2018) is an appropriate term for considering them together. Besides their inevitable nature, they have few other substantial features in common. OFD-sows are destroyed instead of ending up being slaughtered and consumed. This results in extra costs for the farmer instead of earning the salvage value from the slaughterhouse. A large proportion of OFD-animals can also be an indicator of poor welfare (Engblom et al., 2007), which makes it of great concern.

2.1.3 RISK FACTORS FOR SOW LAMENESS

The prevalence of sow lameness varies according to housing and management systems, but the associations are not straightforward. Lameness has been reported to be more prevalent in group-housed sows in comparison with sows housed individually in crates (Calderón Díaz et al., 2014). However, opposite results have also been reported: Morgan et al. (2018) found that lameness index of sows improved during gestation in group housing system rather than deteriorated. In practice, lameness of sows housed in individual crates may easily be underdiagnosed. Detecting lameness of sows housed in crates is very unlikely, because they are not seen walking (Chapinal et al., 2010). Actually, housing of gestating sows in individual crates has been banned in the European Union since 2013 (Directive 2008/120/EC). Group housing allows the sows to express normal, species-specific activity and behavior, but even then it does not automatically bring better animal welfare. In particular, attention should be paid to prevention of lameness (Maes et al., 2016). Group housing sets more demands on the function of the locomotor system, as it requires more movement of sows and therefore the locomotor system is used more. Higher quality of stockmanship may also be required for early detection and resolution of problems in group-housing systems (Chapinal et al., 2010).

Floor space per sow, pen design, flooring and group size may affect development of lameness (Maes et al., 2016). Floor properties should give animals the possibility to walk normally instead of forcing them to an altered gait to avoid slips and injury (Von Wachenfelt et al., 2008). The flooring should be non-slippery, non-abrasive and provide a sound footing (Heinonen et al., 2006). The floor types used for pigs are solid, partially slatted and fully slatted floors (Maes et al., 2016). Housing on slatted floors increases the risk for lameness compared with housing on solid floors or outdoors (Heinonen et al., 2006; KilBride et al., 2009). The increased risk for lameness on a slatted floor may come from an increased prevalence of locomotor problems or because locomotor problems are more painful or disturbing for a sow on a slatted floor (KilBride et al., 2009; Maes et al., 2016). The quality of slats, e.g. width and sharpness of edges, may affect the incidence of injuries to the locomotor system. In the above-mentioned study of Calderón Díaz et al. (2014), flooring was one possible explanation for increased lameness in group-housed sows, as the floor slats in the loose house were the narrowest available (80 mm) for sows. The sows were also housed in a dynamic group with new sows entering the group at frequent intervals, which is a potential risk for lameness.

Pluym et al. (2017) studied the possible risk factors for lameness within the first days of group housing and found that an increase in space allowance from 1.7m^2 to 3m^2 decreased the risk of lameness. The sows were moved from individual stalls to group housing four weeks after artificial insemination. It was also found that dirty sows (>10% of body surface covered by feces) had an increased risk for developing lameness. The explanation for lame sows becoming dirty may be that they were recumbent more often, or they were lying in wet places because they found it too hard to compete for better, drier areas. The highest percentages of dirty sows were found from farms with the dirtiest floors. However, floor dirtiness was not retained in the statistical model, indicating that dirty floors were not causing higher risk for lameness development in this study (Pluym et al., 2017).

2.2 LAMENESS SCORING

2.2.1 SUBJECTIVE METHODS

Visual locomotion scoring is probably the most common method used to assess lameness. The principle is that animals are assigned a score while standing and walking based on aspects of their gait, posture and behavior (Pluym, 2013c). Scores are assigned on a numerical rating scale (NRS) or a visual analogue scale (VAS). A NRS uses discrete ordered categories (D'Eath, 2012) whereas a VAS scores lameness on a continuous scale (Nalon et al., 2013). In practice, a VAS is usually a 100 mm long horizontal line anchored by the minimum and maximum score at each end. Observers make a mark on the line at the point that represents their perception of the magnitude or extent of the assessed gait, posture or behavioral variable (Pluym, 2013c). Several visual scoring systems have been used in studies for detecting lameness of sows and gilts (Dewey et al., 1993; Karlen et al., 2007; D'Eath, 2012; Grégoire et al., 2013; Pluym et al., 2017). Most of the studies have used ordinal scales, a number of categories ranging from 3 to 10 and score zero representing normal gait. In the 3-step scale of Welfare Quality (2009), there is no "normal gait" score, but the lowest score (zero) combines sows with normal gait and those with some difficulties in walking. This may simplify the classification of subtle lameness cases, but at the same time it gives an impression that the absence of lameness and mild lameness are equivalent from the animal welfare point of view. The protocol itself says that a score zero is awarded where welfare is good.

Visual scoring is a useful, quick and affordable way to quantify lameness prevalence on a farm (Nalon et al., 2013). However, the method is highly subjective and dependent on the scorer being sufficiently knowledgeable. To make users both accurate and precise when evaluating sows for lameness, visual scoring requires substantial training (Abell et al., 2014). Overall, visual scoring systems are of only limited reliability (Nalon et al., 2013). Limitations arise because of individual variation and lack of consistency over time and inter- and intra-observer bias. Inter-observer reliability is determined, for example, by professional profile of the assessor, the prevalence of the condition, the testing situation and the number of animals in a scoring session (D'Eath, 2012). The testing situation can also expose visual scoring of lameness to bias, as pigs alter their gait in accordance with flooring conditions. It has been reported that in comparison to clean floors, pigs reduced walking speed, shortened stride length and prolonged their stance (i.e. limb in contact with ground) time when walking on fouled floors (Von Wachenfelt et al., 2008). It is very likely that slatted floors also affect the gait of pigs. Therefore, the lameness scoring should be done on clean, solid floors. In fact, the ease and cheapness of the visual scoring is slightly questionable. If it is conducted properly, sows may have to be removed from their pens to be walked elsewhere, which is time consuming.

2.2.2 OBJECTIVE METHODS

Force plates, kinematics, positioning and accelerometers are examples of the more objective methods and devices used to assess sow lameness. Mohling et al. (2014) used embedded force plates and gait analysis walkway systems to detect lameness of sows. Lameness was induced with an injection of Amphotericin B in the distal interphalangeal joint of both claws in one hind foot. Amphotericin B is an antifungal drug that produces a transient, chemical lameness when it is injected into a joint (Karriker et al., 2013). For force plates, weight distributions on each foot were collected; and for gait analysis, stride time (time between two footfalls by the same foot), stride length (distance between two sequential footfalls by the same foot), maximum pressure (greatest weight placed on a single foot) and stance time (duration of time the sensors were activated by a foot in a single stride). Results showed that stride time increased for all feet, stride length and maximum pressure placed on the induced feet decreased and stance time increased for all sound feet after lameness induction (Mohling et al., 2014).

Stavrakakis et al. (2015) evaluated walking kinematics of pre-breeding gilts and sows in a case-control study. Gait alterations during visually diagnosed lameness were evaluated to identify the best quantitative lameness indicators. It was found that lameness was especially detected using vertical head displacement and asymmetric stride phase timing. In the study, animals were subjected to a kinematic motion capture, where they walked on the concrete walkway. An array of infra-red cameras collected the three-dimensional coordinate data of reflective skin markers attached to the head, trunk and limb anatomical landmarks.

Traulsen et al. (2016) tested ear sensors to sample positioning and acceleration to detect spontaneous lameness in group-housed sows. The path length walked and number of 25x25cm squares visited by a sow during the day and variance of acceleration measurement during the day were calculated. During the observation period, all the lameness cases noted by the farm staff were presented to veterinarians, who made the diagnosis and decision about the treatment. In addition, the sows were scored for lameness weekly. The data on lameness treatments of the sows and lameness scorings were used as reference systems. Analysis showed that the walked distance per day per sow diminished several days before a lameness treatment occurred, and to a smaller extent before lameness score 2 (severe lameness) was observed. For the index acceleration, there was no obvious difference between the lame and non-lame periods. According to the research, after installing the receiver, ear sensors are an easy-to-use method to detect changes in movement behavior of lame sows for commercial farms too, but further improvements are still needed (Traulsen et al., 2016).

Grégoire et al. (2013) compared five methods to evaluate lameness of sows housed either in gestation stalls or individual pens: footprint analysis, kinematics, accelerometers, lying-to standing transition and foot lesion observation. The methods were compared among themselves and with visual scoring. Kinematics revealed that lame sows had lower walking speed and longer stance-time than non-lame sows. Accelerometer measurement showed that lame sows spent less time standing, laid down earlier after feeding, and tended to step more often during the hour after feeding than non-lame sows. Footprint analysis, observation of lying-to standing transition and foot lesions did not detect significant differences between lame and non-lame sows.

Currently, the more objective methods are mainly restricted to research settings (Nalon et al., 2013). Using force plates or kinematics requires specific and quite complex installations in the barn. It is mentioned in the paper of Stavrakakis et al. (2015) that the methodology of the study took typically two hours per animal for motion capture and initial data processing. Placement of the kinematics markers is critical and should be repeatable, animals may need to be habituated to the set-up and they may need to walk straight with steady pace and constant speed. In addition, the results of the above-mentioned studies are not in total agreement. For example, Grégoire et al. (2013) reported the walking speed to be lower in lame sows, whereas no difference was detected in walking speed between lame pigs and their controls in another study (Stavrakakis et al., 2015). On the whole, the automatic lameness detection systems require further validation and improvement to become usable as practical applications.

2.3 DIAGNOSIS AND CAUSES OF SOW LAMENESS

Lameness can have several causes, such as arthritis, fractures, osteochondrosis, trauma, claw and skin lesions and anatomical impairment (Dewey et al., 1993; Kirk et al., 2005; Heinonen et al., 2006; Engblom et al., 2008).

As mentioned already, it is difficult to get an exact diagnosis of lameness in a sow under field conditions. Herd-level clinical examination of the musculoskeletal system is not very specific as the diagnosis should be reached using only history, lameness assessment, visual inspection, palpation and measurement of a body temperature. In other domestic animal species, ultrasound, X-ray and other diagnostic imaging methods are commonly used in the examination of a lame patient. For equine lameness examination, flexion and extension tests, selective perineural anesthesia, and intra-articular anesthesia are used to isolate a focal area of pain. Subsequently, this area of pain is intensively examined to determine the exact diagnosis (Desrochers et al., 2001). Pig practitioners are encountering the same challenges as cow practitioners in the field: they rarely have access to clinical equipment, facilities and diagnostic imaging machinery and interpretation experts needed (Chamorro et al., 2019). Patients are not trained to be tied and to walk and trot in a controlled manner, they often do not tolerate limb handling and they are housed on surfaces that represent a high risk for falling (Desrochers et al., 2001). In sows, post-mortem examination is often necessary to differentiate the various causes of lameness. The combination of a clinical examination and a gross post-mortem examination has been determined to be a good method for diagnosing the cause of lameness of an individual sow (Dewey et al., 1993). The method naturally serves only future interests of the farm and other sows on the farm, and does not help a particular lame sow. Unfortunately, scientific research combining clinical and post-mortem examination of sows has not been done after Dewey et al. (1993).

Pathological-anatomical diagnoses (PAD) of removed sows have been investigated in a few studies (Dewey et al., 1993; Kirk et al., 2005; Sanz et al., 2007; Engblom et al., 2008). The most common PADs associated with the locomotor system and the prevalence of PADs in these studies are presented in Table 1. Of the studies, Dewey et al. (1993) performed a clinical and post-mortem examination of 50 sows culled for lameness. Kirk et al. (2005) did not report the pre-mortem signs of sows, leaving the association with lameness unclear. However, from a total of 172 euthanized sows sent for necropsy, 72% had a lesion in the locomotor system as a main cause of killing. Of the 35 sows also subjected to a histological examination, 17 (49%) had evidence of osteochondrosis in the epiphyseal cartilage in one or more joints. As a secondary diagnosis, arthrosis and claw lesions were observed frequently. Arthrosis was almost a constant secondary diagnosis for both the spontaneously dead (92.5%) and the euthanized sows (88%). Overgrown heels were the most frequent claw lesion. Spontaneously dead sows (n=93) were also included in the study, but none of them had a primary PAD associated with the locomotor system. The study of Engblom et al. (2008) was conducted in a large herd, where 96 carcasses of sows found dead or euthanized were examined. Arthritis, with an incidence of 36.4%, was the most common PAD. Almost all arthritis cases (34 out of 35) were chronic, purulent type and commonly found in elbow, stifle and/or shoulder. Of the fracture-cases 80%, and of the arthritis-cases 77% were reported to be lame. In this study, all primary PADs associated with the locomotor system were in the euthanized sows.

Table 1. The locomotor system related primary pathological-anatomical diagnoses and their prevalences (%) in removed sows in four studies done between 1993 and 2008.

	Arthritis	Fracture	Osteo-chondrosis	Arthrosis	Osteo-myelitis	Arthrosis as a secondary diagnosis	n
Dewey et al., 1993[A]	22	2	34[1]	12		-	50
Kirk et al., 2005[B]	24	16	-	8[2]	18	88	172
Sanz et al., 2007[C]	17	-	3	-	-	-	107
Engblom et al., 2008[D]	36	10	14	-	-	-	96

[A]Sows from ten farms, all culled for lameness

[B]Euthanized sows from ten farms, pre-mortem signs not reported

[C]Sows from one farm, found dead or euthanized for several reasons

[D]Sows from one sow pool, found dead or euthanized for several reasons

[1]Osteochondritis dissecans or epiphysiolysis

[2]Osteochondrosis included

2.3.1 ARTHRITIS

Arthritis is defined as inflammation of the intra-articular tissue of a joint. Infectious arthritis in pigs is commonly caused by bacteria, originating from bacteremia, direct inoculation of bacteria into the joint, or extension of a local infection into the joint (Andersen & Mulon, 2019). The bacteria isolated from infected joints of pigs include *Erysipelothrix rhusiopathiae, Haemophilus parasuis, Streptococcus* and *Staphylococcus* species, *Actinobacillus suis, Mycoplasma hyosynoviae* and *M. hyorhinis* and *Trueperella pyogenes* (Gomes Neto et al., 2011; Madson et al., 2019). Many of the above-mentioned bacteria may also cause several signs and diseases other than arthritis. Arthritis is characterized by increased volume of synovial fluid, the features of which may differ depending on the cause. The features include color, turbidity, hemorrhage and exudate, which may be, for example, purulent, serous or fibrinous (Gomes Neto et al., 2011).

Typical clinical signs of arthritis are acute non-weight-bearing lameness, swelling of the joint and pain and heat on palpation of the joint. One or several joints may be affected at the same time and the animal may also have fever and anorexia (Desrochers & Francoz, 2014). There is hardly any research on arthritis in sows, but some features of arthritis in other species are likely applicable to sows also. In beef cattle, septic arthritis of the distal interphalangeal joint has been studied in order to find if factors of clinical history and physical examination are associated with the diagnosis. It was found that the lameness score of ≥4 (on a scale of 1 to 5) and the presence of asymmetric swelling in the coronary band were closely associated with arthritis (Chamorro et al., 2019). In the study of Engblom et al. (2008), 43% of the sows with arthritis as PAD were suspected of having a fracture based on clinical signs. This indicates that arthritis typically causes very severe lameness in sows.

2.3.2 OSTEOCHONDROSIS

Osteochondrosis is a non-infectious, degenerative, abnormal condition of the cartilage (Madson et al., 2019), which is caused by a focal disturbance in endochondral ossification as a result of failure of the blood supply to epiphyseal growth cartilage (Olstad et al., 2015). Besides pigs, it occurs in many animal species and human beings (Ytrehus et al., 2007). Osteochondrosis has several manifestations, from *osteochondrosis latens,* where joint lesions are only microscopically visible, to epiphysiolysis, where the proximal head of a bone is separated. *Osteochondrosis dissecans* refers to a cleft formation through articular cartilage, forming a cartilage flap or loose body in the joint. In pigs, lesions are typically found in the distal condyle of the humerus and the medial condyle of the femur, in the semilunar notch of the ulna and in the distal ulnar physis (Ytrehus et al., 2007). Osteochondrosis is a disorder of a growth cartilage, so it usually affects pigs from six to 20 weeks of age, but it can affect pigs up to 18 months of age. Osteochondrosis is very common in the domestic pig breeds: nearly all fattening pigs have some typical lesions in their joints (Etterlin et al., 2017). The research has mostly dealt with growing pigs, but lesions may also be common in sows. Ryan et al. (2010) reported 100% prevalence of osteochondrosis in 36 slaughtered sows. Shifting joint pain is a clinical sign of osteochondrosis (Madson et al., 2019), but the clinical diagnosis is particularly difficult, if not impossible, to make in a living sow (Heinonen et al., 2006).

Osteochondrosis of pigs has been under intensive research since the 1970's, but many aspects of the disease remain undetermined. Clinical relevance of osteochondrotic lesions in sows needs further clarification, and the association between lameness and osteochondrosis is confused. Many studies have not found association between osteochondrotic lesions and lameness (Ryan et al., 2010; Etterlin et al., 2015; Bertholle et al., 2016). Lesions are typically bilateral (Ytrehus et al., 2007; Bertholle et al., 2016), which can make the detection of lameness more difficult, as animals with pain in more than one leg may not appear to be clinically lame. The time span from the formation of a primary lesion to clinical disease may be relatively long (Ytrehus et al., 2004). In addition, not all osteochondrotic lesions develop into clinical disease. The majority of the lesions may heal completely (Olstad et al., 2014), whereas some of the lesions become permanent. It has been hypothesized that in pigs the lesions can no longer be repaired after 13 weeks of age as vascularization of the cartilage tissue has disappeared (Ytrehus et al., 2004). The lesions that have not repaired give rise to osteoarthritis (Fukawa & Kusuhara, 2001), which is also termed degenerative joint disease or arthrosis.

Definitions and terminology around osteochondrosis and its sequel are not strictly defined. It seems that the terms osteochondrosis and arthrosis are used quite ambiguously in the literature, and also joint lesions that are found after the growing phase of a pig are named osteochondrosis. The studies presented in Table 1 give an insight into this differing terminology. In the study of Kirk et al. (2005), the presence of a non-inflammatory joint lesions was diagnosed as arthrosis, which included osteochondrosis. Some sows in the study were sampled for histological evaluation; for those sows, the diagnosis of osteochondrosis was based on histological findings, such as thickening and invagination of the articular cartilage. In the study of Dewey et al. (1993), the diagnosis of arthrosis included fibrillation of the joint cartilage, ulceration of the articular surface and osteophyte production. The diagnostic lesions of osteochondrosis were either *osteochondritis dissecans* or epiphysiolysis. Microscopic lesions of osteochondrosis were found from nearly every sow in the study, but not all them were primarily diagnosed osteochondrosis or arthrosis. In other words, changes in articular cartilage have been defined to be either arthrosis or osteochondrosis in different studies. However, microscopic osteochondrotic lesions have not always meant that osteochondrosis would be the PAD of an animal, which is reasonable. Dewey et al. (1993) concluded that osteochondrosis should only be identified as the cause of lameness if the lesions are found in a joint of the clinically affected leg and only after other causes of lameness have been ruled out. This means that the exact diagnosis of osteochondrosis can only be made with a combination of clinical and post-mortem examination.

2.3.3 CLAW LESIONS

Claw lesions are of various types, such as overgrowth (toes, heel), erosion (heel) and cracks (heel, white line, sole/heel junction, claw wall) (reviewed by Nalon et al., 2013). Lesions are mainly found on the outer claws (Kroneman et al., 1993) and are highly prevalent in sows. Almost every sow out of 421 had claw lesions in a study of Pluym et al. (2011). Other studies have also reported high prevalence (Kirk et al., 2005; Knauer et al., 2007). Knauer et al. (2007) evaluated the physical condition of culled sows in two U.S. harvest plants. Of 3158 sows visually inspected post-mortem, 86% had at least one claw lesion impacting at least one foot.

Although a high number of sows have claw lesions, not all sows will demonstrate lameness (Pluym et al., 2013a). Kroneman et al. (1993) found no association between the incidence of claw lesions and lameness at the level of an individual animal, whereas Gjein & Larssen (1995) reported that risk of lameness increased with increasing claw lesions score and claw infections. It has been estimated that 5–20% of lameness might be due to claw lesions (Dewey et al., 1993). In the Finnish study of Heinonen et al. (2006), claw lesions were the clinical diagnosis of every fourth lame sow. In this study, the prevalence of lameness was 8.8% among 646 loose-housed sows and gilts.

Claw lesions can be assessed in living animals (Nalon et al., 2013), but the usefulness of scoring techniques is limited. Lesions can be scored in the farrowing crates when a sow is lying or with a standing sow by lifting the leg. A claw may have to be cleaned before the scoring is possible. Lifting the leg often requires restraint, for example with a snare loop around the upper jaw, which is potentially stressful for a sow (Van Riet et al., 2019).

2.4 TREATMENT OF SOW LAMENESS

No controlled trials or current care guidelines can be found about treatment of sow lameness. As evidence-based guidelines do not exist, the decisions about treatment are mostly based on clinical experience. The possible lack of exact diagnosis obviously complicates choosing the right treatment, and in most cases the treatment is symptomatic, i.e. aiming to relieve the symptoms without addressing the underlying cause of the disease. In practice, treatment consists of medication, usually antimicrobials with or without analgesics, and supportive care, like moving the patient to a hospital pen. In any case, proper treatment of lameness requires extra work.

Many diagnoses behind lameness are common to several domestic animal species and the guidelines for treatment can be obtained from the literature concerning other species. However, economic considerations, withdrawal time and rules about production animal medication may often preclude the treatment in sows. The first thing to determine is whether the lame sow can be cured or whether slaughter or euthanasia is a better solution. For example, infected claw lesions and arthritis of sows are often detected at a severe or chronic stage when the animal is clearly lame and when treatment is frequently ineffective (Pluym et al., 2013a). Osteochondrosis and degenerative joint disease are also said to be typically unresponsive to treatment (Rowles 2001). In horses, in comparison, lesion debridement and curettage by an arthroscopy represent the standard treatment for *osteochondrosis dissecans* (Clarke et al., 2015). It is questionable to compare sows and domestic cats, but it is anyway worth mentioning that the degenerative joint disease of cats is not seen as impossible to treat successfully. Instead, studies evaluate options for the treatment of disease, like long-term use of NSAIDs and modifying the environment of the sick cat (Kerwin, 2010). It sounds uncompromising to say that porcine osteochondrosis is unresponsive to treatment, but the scientific literature really says nothing about the treatment of the condition. As osteochondrotic lesions of pigs can heal completely (see section 2.3.2), it could be perfectly appropriate to try symptomatic treatment with a NSAID for the cases that have clinical signs.

Currently, septic arthritis seems to be the only diagnosis for sow lameness for which the literature provides some treatment guidelines. The treatment of septic arthritis consists of wound management, joint lavage and systemic antibiotic therapy (Andersen & Mulon, 2019). In practice, joint lavage is nearly impossible to conduct under farm conditions. The text does not mention anything more specific about the antibiotic therapy. Ideally, the choice of an antibiotic should be based on bacterial culture and sensitivity, but taking synovial samples is not included in routine pig veterinary practice. The Food Safety Authority of Finland and the Veterinary Faculty of the University of

Helsinki have together given recommendations for the use of antimicrobials in domestic animals. Benzyl-penicillin is the drug of choice for treatment of arthritis of pigs in these recommendations, or tylosin, lincocin or tiamulin in the case that mycoplasma is suspected; amino-penicillins and tetracyclines are mentioned as the secondary choice (Anonymous, 2016). The duration of antibiotic treatment for the arthritis of a sow remains empirical. In Finland, the common practice is that the duration of antimicrobial therapy for sows is 1–7 days.

Septic arthritis is a major problem in horses too, and the treatment is often rigorous. In horses, a prolonged systemic antimicrobial treatment is indicated (e.g., 10–14 days), combined with debridement by arthrotomy or arthroscopy and joint lavage, often done under general anesthesia and repeated several times (see review by Haerdi-Landerer et al., 2010). Despite intensive treatment, the prognosis is still guarded. In humans, the duration of antimicrobial treatment for bacterial arthritis is usually a minimum of two weeks, and it is combined with arthroscopic drainage of the affected joint (Smith et al., 2006). In comparison to these, 1–7 days of systemic antimicrobial therapy without any surgical interventions, which is the commonly used treatment for arthritis of sows, seems rather insufficient. As the efficient treatment of septic arthritis is time-consuming and expensive, the search for new therapeutic procedures for large animals continues. Local application of a slow release formulations of antimicrobial drugs has given promising results, but this treatment may also be out of reach for lame sows. The drug-delivery systems have to be implanted in joints, which probably requires general anesthesia (Haerdi-Landerer et al., 2010). Possible antimicrobial residues may also inhibit the use of these products in food-producing animals. In fact, the worldwide concern about the increasing antimicrobial resistance is making the use of antimicrobials in animals more and more questionable.

2.4.1 TREATMENT OF PAIN

Independent of exact diagnosis, lameness is often associated with pain and there is a moral obligation to minimize pain in animals. As the American College of Veterinary Anesthesiologists (ACVA, 1998) emphasizes, there are no beneficial effects of unrelieved pain in animals under veterinary care. Analgesia is a symptomatic treatment for a lame sow. Still, there are large differences in the frequency of use of pain alleviation among veterinarians (Raekallio et al., 2003), although both veterinarians and farmers have a positive attitude towards pain relief in pigs (Ison & Rutherford, 2014). The use of pain relief in production animals is limited by practical, historical, cultural, economic and legislative considerations, and clearly there is a need to facilitate and rationalize the use of analgesics in production animals as part of everyday management (Guatteo et al., 2012). Potential barriers to the increased pain relief application are difficulties in recognizing pain and lack of knowledge of how to treat it (Flecknell, 2008; Hewson et al., 2007).

Two nonsteroidal anti-inflammatory drugs (NSAID), meloxicam and flunixin meglumine, have demonstrated efficacy in pain mitigation associated with lameness in pigs and sows. Friton et al. (2003) found a reduction in lameness after the injection of meloxicam (0.4 mg/kg) in pigs (gilts, sows and finishers), using a clinical lameness scoring system. More recently, Pairis-Garcia et al. (2014) demonstrated the effectiveness of flunixin meglumine injection (2.2 mg/kg) and oral meloxicam (1.0 mg/kg) in reducing pain in sows with induced lameness, using nociceptive threshold tests. On the other hand, the effect of a single intra-muscular injection of meloxicam on lameness variables was only limited, when force plate, kinematics and accelerometer tools were used to assess lameness. The stepping frequency of hind legs however decreased and standing time after feeding increased after meloxicam, indicating an improvement of the lameness condition and analgesic effect of meloxicam (Conte et al., 2015).

Ketoprofen is a NSAID that is widely used for production animals because of its anti-inflammatory, anti-pyretic and analgesic effects (Mustonen et al., 2012). In the European Union, ketoprofen is included in the Annex II of Maximum Residual Limit (MRL) Regulation, meaning that ketoprofen is not subject to MRLs (EMEA, 1996). The recommended dosage for intramuscular use in pigs is 3 mg/kg. The oral solution of ketoprofen has marketing authorization in several EU countries for the treatment of fever and dyspnea associated with respiratory disease in fattening pigs at a dose rate of 1.5–3 mg/kg (Veterinary Medicines Directorate, 2018). Oral ketoprofen has been reported to be well absorbed in pigs and having almost complete bioavailability (Raekallio et al., 2008). There are no scientific reports about the use of oral ketoprofen for sows. In a study of Pairis-Garcia et al. (2014), meloxicam was administered to sows orally in cookie dough. Unfortunately, the paper did not discuss the pros and cons of the oral administration of the medication.

2.4.2 SUPPORTIVE CARE

Good care of lame sows does not consist of the medication alone. One approach for on-farm lameness and pain management is husbandry and management tools to provide supportive care for sick animals.

In the EU, most sows are kept in fully or partly slatted housing systems (SVC, 1997). These housing systems are durable and offer advantages concerning hygiene and labor, but provide little comfort to sows (Tuyttens et al., 2008). Supportive care may include providing additional bedding or a rubber mat to create a more comfortable area for lying and resting (Elmore et al., 2010; Pluym et al., 2013a). Rubber mat use has become popular in the dairy industry, but mats have been used to a lesser extent in the pig industry (Tuyttens et al., 2008). Limited recommendations are available about the durability, placement, installation and management of mats in sows (Campler et al., 2016). The studies assessing the impact of rubber mats on sow welfare have shown sows' preference to rest on rubber mats compared with bare concrete floors and an increased recumbent lying behavior instead of sternal lying posture (Tuyttens et al., 2008; Elmore et al. 2010). Pigs prefer to lie down and rest in fully recumbent lying posture, with limbs extended, when housed in thermoneutral conditions and given enough space (Ekkel et al., 2003). Thus, mats may add comfort by their insulating properties too. In low temperatures pigs adopt sternal lying postures, because it minimizes their contact with and transfer of heat to the floor (Tuyttens et al., 2008).

According to Finnish legislation, sick pigs are required to be treated appropriately, and there has to be a hospital pen on the piggery reserved for sick and injured pigs (Animal Welfare Act, 1996). It is known from practical experience that hospital pen should be in a place, where animals can be moved to and watched effortlessly and where they are easy to feed and keep clean. In Denmark, legislation specifies how a hospital should be designed: the requirements include soft bedding, possibility of behavioral thermoregulation and extra space allowance (Thomsen et al., 2016). Still, it seems that the use of hospital pens has not become properly established in pig production. During recent years most cases of non-compliance with legislation at Danish pig farms have been related to the issue. Surprisingly, lack of time or labour are not the major obstacles to the use of hospital pens. The most frequently stated reason why sick pigs were not moved to hospital pens was "not considered necessary" (Thomsen et al., 2016). Pig farmers seem to have different thresholds for defining pigs sick enough to need housing in hospital pen or other supportive care. This indicates that there is a need for better definitions and guidelines for appropriate treatment of sick pigs.

2.5 SICKNESS BEHAVIOR

Behavior is the way in which the animal expresses its basic needs, deficits and happiness. Changes in behavior are visible and rapid, which make them a useful tool for the assessment of animal welfare (Deen, 2010). Health challenges may lead to changes in animal behavior (Hart, 1988; Weary, 2009). Typical behavioral changes in connection with acute illness in animals include a reduction in activity, social interaction, feeding and drinking behavior, as well as an increase in huddling, shivering and resting (Millman, 2007). These changes, referred to as sickness behavior, generally accompany fever response (Hart, 1988), which is typically associated with infectious diseases. Sickness behavior is argued to be part of a strategy to fight disease, where reduced activity helps the animal to conserve energy and combat pathogens (Deen, 2010).

Recognizing behavioral changes in lame sows would make it easier to detect lameness of individual sows. Besides, with the present practice of rearing sows in groups, understanding the behavioral needs of lame sows would help to improve facility design and management protocols, to ensure that all compromised animals have sufficient access to food, water and a lying area (Pairis-Garcia et al., 2015a).

The studies researching behavior changes of lame sows have reported some findings. Grégoire et al. (2013) found that severely lame sows spent less time standing and lay down earlier after feeding compared to moderately lame and non-lame sows. Similar results were found when lameness was induced for sows using a chemical synovitis model: the frequency of standing postures significantly decreased and lying postures increased 24–72 h after lameness induction (Pairis-Garcia et al., 2015a). Bonde et al. (2004) studied lying down postures of sows and found that difficulties in lying down were associated with lameness. Pairis-Garcia et al. (2015a) supposed that lame sows chose to remain lying for longer periods to avoid potentially painful lying down events.

Lameness may also have very prolonged effects on behavior of pigs. Munsterhjelm et al. (2015) found that feed intake decreased already 2–3 weeks before diagnosis in future lame pigs, when health records and changes in individual, voluntary feed intake of growing pigs between 40 and 120 kg were determined. The question of whether the onset and extent of the behavioral changes are related to the size of the health challenge remains largely unanswered (Szyszka & Kyriazakis, 2013), although Munsterhjelm et al. (2015) reported a substantially more severe anorexia associated with lameness than with acute tail biting lesion, indicating that lameness affected the welfare of affected animals more than being tail bitten.

3. AIMS AND HYPOTHESES OF THE STUDY

The overall aim of this thesis was to gather information and add to the scientific knowledge on sow lameness. More knowledge is needed of the exact causes and treatment of lameness and of the significance of lameness for sows. The specific aims of this study were:

1) to describe pathological-anatomical findings in euthanized and spontaneously dead (referred to together as on-farm-dead, OFD) sows with an emphasis on the locomotor system (Study I)

2) to examine the efficacy of oral ketoprofen in the treatment of non-infectious lameness in sows (Study II)

3) to determine the effect of lameness and lameness-related pain on the behavior of sows (Study III)

The main hypotheses of the studies were that

1) lesions in the locomotor system are common in OFD sows (Study I)

2) non-infectious lameness of sows is associated with pain and thus administration of ketoprofen, an analgesic drug, decreases the lameness (Study II)

3) lame sows are more passive than healthy control sows. It was hypothesized, that changes in behavior are often caused by pain, and thus administration of ketoprofen to lame sows decreases the behavioral differences.

4. MATERIALS AND METHODS

The summary of the study design, study animals, examinations performed and statistical analyses are presented in this chapter. Study designs and sample sizes are summarized in Table 2. The details of materials and methods for the studies (I-III) are available in the original articles included at the end of the thesis.

All study sows originated from privately owned farms in southern or southwestern Finland. In addition to sows, gilts were included, if they were old enough to be inseminated. Both sows and gilts are referred to as sows later in the text, unless otherwise mentioned. The sows were under normal management practices of the farms during the studies and all the farms belonged to the national level of the Finnish herd health classification scheme, Sikava (2017). These herds need to prove their freedom from swine enzootic pneumonia, salmonellosis, sarcoptic mange, swine dysentery and progressive atrophic rhinitis. In addition to this, Finland is free from classical and African swine fever, Aujeszky's disease, PRRS (porcine reproductive and respiratory syndrome) and TGE (transmissible gastroenteritis) (Finnish Food Authority, 2019).

Table 2. Summary of the sows examined, study designs and sample sizes in the original studies (I–III).

	Study I	**Study II**	**Study III**
Study design	*Prospective, descriptive study*	*Randomized, double-blinded, controlled, clinical field trial*	*Randomized, double-blinded, controlled, clinical field trial*
Number of animals	65 found dead 27 euthanized 38	282 lame 141 - ketoprofen 4 mg/kg 46 - ketoprofen 2 mg/kg 47 - placebo 48 healthy control 141	26 lame 13 - ketoprofen 4 or 2 mg/kg 9 - placebo 4 healthy control 13
Number of farms	*15*	*10*	*1*

The data were collected from volunteer farms, the owners of which were willing to provide the research group with the chance to carry out investigations on their farms. In addition, they provided the researchers with sow carcasses and the necessary anamnestic information needed for the studies. The recruitment process included active contacting of farms by different operators in the business, including the research team, slaughterhouse personnel and the national pig producers' organization.

Study II complied with Good Clinical Practice (GCP) guidelines and the study protocol was approved by the Ethical Committee of the University of Helsinki. Study III was conducted within the protocol of Study II. Study I did not need ethics approval as all the animals entered the study after death.

4.1 STUDY DESIGN AND SAMPLE SIZE

4.1.1 PATHOLOGICAL FINDINGS IN SPONTANEOUSLY DEAD AND EUTHANIZED SOWS (STUDY I)

Study I was a prospective, descriptive study to determine the pathological-anatomical diagnoses (PAD) of OFD sows. In this thesis, the focus of this study was on the pathological findings in locomotor system. The findings were obtained through a post-mortem examination, and the general information on the sow was collected through a questionnaire. Originally, we aimed to collect all dead and euthanized sows of ten herds for one year. We calculated that with an average of 100 sows in a herd and an average mortality of 8%, we would be able to obtain about 80 sows. However, we were not able to motivate the farmers to send in all their dead sows for a year, and therefore we had to include more herds in the study. Finally, the study was conducted with a convenience sample of 15 Finnish farms, and the sample consisted of 38 euthanized sows and 27 sows which were found dead. Later in the text, both euthanasia and spontaneous death are referred to as death, unless otherwise mentioned.

4.1.2 EFFECT OF ORAL KETOPROFEN IN TREATMENT OF LAMENESS (STUDY II)

Study II was a randomized, double-blinded, placebo-controlled, clinical field trial. For treatment of lameness, two doses (2 and 4 mg/kg) of oral ketoprofen were compared to placebo over five consecutive days following enrollment into the study. For the sample size calculation, the expected difference in efficacy between groups treated with ketoprofen and placebo was 25% (Friton et al., 2003). With a one-tailed test and a statistical power of 80%, the required sample size was 47 lame animals in each of the three groups. The trial was conducted until the sample size required i.e. altogether 141 lame sows, was achieved. Finally, the data for the sows were collected from ten farms.

4.1.3 BEHAVIOR CHANGES ASSOCIATED WITH LAMENESS (STUDY III)

Study III was a randomized, double-blinded, placebo-controlled, clinical field trial to determine the effect of lameness and lameness-related pain on behavior of sows. The sample consisted of 13 lame sows and 13 healthy control sows. The study was conducted in one farm parallel with Study II, using a subset of the animals included in the Study II. This particular farm was chosen for Study III as the pen design and the location of all the study sows in one room of the piggery made it possible to make direct behavior observations in the farm. Every sow included in the Study II in this farm was taken into Study III.

4.2 EXAMINATIONS

4.2.1 POST-MORTEM EXAMINATION AND THE DEFINITION OF DIAGNOSES (STUDY I)

Post-mortem examinations (PME) were performed according to a standard operating procedure at the Finnish Food Safety Authority in Seinäjoki (n=23), at the University of Helsinki (n=37), at the University Ambulatory Clinic in Mäntsälä (n=3) or on the farm (n=2). Samples for histology were taken from heart, lung, liver, kidneys, urinary bladder, uterus and affected internal organs.

Abnormalities in big joints were described in detail, according to criteria presented in Table 3. Cloudy or purulent synovial fluid and changes of synovial membrane indicative of inflammation were regarded as inflammatory arthritis. The presence of gross lesions (at least erosion or thinning of the joint cartilage) in one or more joint surfaces without changes indicating an acute inflammation of the joint was regarded as degenerative joint disease. Mild cases with only color changes, mild thickening of synovial membranes or an increased amount of joint fluid were regarded as other joint disease.

Table 3. The criteria for describing joint findings in Study I.

Joint	Synovial fluid	Synovial membrane	Joint surface

• Shoulder (humeral)
• Elbow (humeroulnar and humeroradial)
• Hip (coxofemoral)
• Knee (femorotibial and femoropatellar)
	Amount
	• normal
	• abnormal, increased
	
	Appearance
	• normal
	• abnormal
	  o clear
	  o cloudy
	  o reddish
	  o purulent
		Appearance
		• normal
		• abnormal
		  o reddish
		  o proliferated
		  o folded
			Appearance
			• normal
			• abnormal
			  o uneven
			  o eroded
			  o craters
			  o detached pieces of joint cartilage
			  o changes indicating trauma

For each sow, pathological findings were classified according to their assumed role in the process leading to death or euthanasia. The main cause of death was considered the primary pathological-anatomical diagnosis (PAD-1). PAD-2 was defined as a secondary pathological-anatomical diagnosis, assumed to be less important than or preceding PAD-1. Other PME findings, which logically could have contributed to the health status of the sow but were not directly related to death, were considered incidental findings. In general, lesions were considered inflammatory when macroscopic changes including purulent exudate or severe hyperemia were evident, or the finding could be confirmed by histopathological examination.

4.2.2 PRE-MORTEM SIGNS AND CIRCUMSTANCES OF SOWS (STUDY I)

A questionnaire was used to collect general information about the sow and clinical signs and circumstances preceding her death. The questions were selected based on the literature and clinical experience of the research group. Qualitative questions were mostly closed, but free text was allowed. The information was collected by telephone by one researcher, except in a few cases the questionnaire was completed by the farmer and mailed.

4.2.3 PROCEDURES IN STUDIES II AND III

Timeline for all procedures performed in Studies II–III is presented in Figure 1.

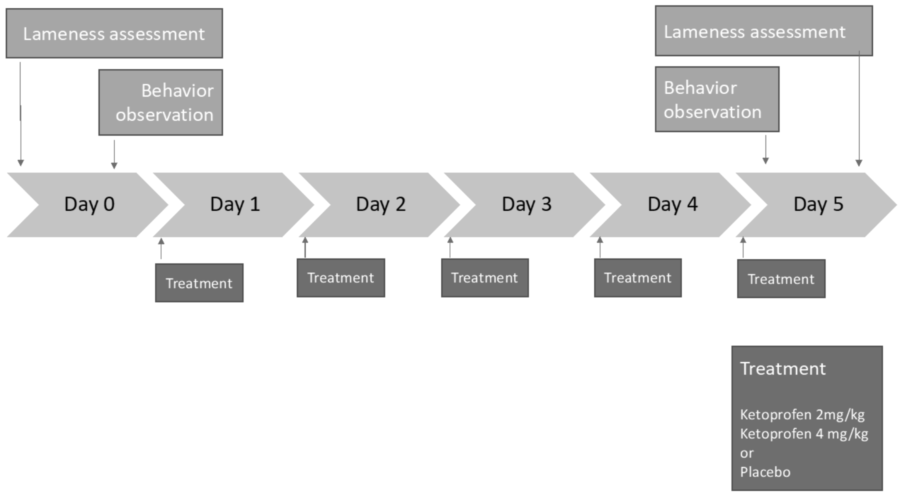

Figure 1. Timeline for procedures in studies investigating the effect of ketoprofen in treatment of lameness and the association between lameness and behavior of sows (Studies II–III).

Inclusion criteria, lameness assessment and enrollment into study (Studies II and III)

Loose-housed dry sows and gilts which had been inseminated at least once, but pregnant for <100 days were eligible for the study. Sows medicated with NSAIDs, glucocorticoids or antimicrobials within 14 days of the start of the study were excluded.

To find the lame sows for the study, the locomotion of sows was first investigated for 2–5 minutes in a group in their own pen. Animals with abnormal gait were selected for individual lameness assessment. Two veterinarians independently assessed lameness using a five-grade lameness scoring scale (Table 4) while the animals walked on a hard, solid floor for at least 10 m. The sows were driven to walk by clapping them on the back and guiding with plastic boards. The animals with a lameness score ≥2 identically assessed by both veterinarians were included in Studies II–III.

The cause of lameness was limited to non-infectious cases. The diagnosis was based on a thorough clinical examination including inspection and palpation of the lame leg and the measurement of rectal temperature and, retrospectively, on the analysis of haptoglobin from a blood sample. The sows having rectal temperature >39.5°C, fractures, infected leg wounds or any concurrent disease were excluded from the study.

A clinically healthy, non-lame control sow at the same stage of pregnancy was selected for each lame sow from the same pen to compare haptoglobin concentrations and to serve as a healthy control sow in Study III. The control sows were examined similarly as the lame sows, but they were not treated.

Table 4. Lameness scoring system used to assess lameness of sows in Studies II–III.

Score	Lameness	Clinical signs
0	None	No lameness
1	Minimal	Stiff, ataxic or swaying gait, shortened stride
2	Slight	Limp visible, but animal unconcerned and exercises normally
3	Moderate	Obvious limp present all the time (with head bobbing), animal having some difficulty with exercise, moderate kyphotic posture
4	Severe	Animal barely weight bearing/not weight bearing, severely lame but able to move, severe kyphotic posture

Twenty-one lame sows were excluded from the study, leading to 141 lame sows being included in the final analysis. Fourteen sows were excluded because of a fracture, an infected leg wound, a body temperature >39.5°C or other concurrent disease. Seven sows were excluded because of a protocol violation.

Blood sampling and haptoglobin analysis (Studies II and III)

A blood sample was taken from the saphenous or tail vein of each study animal after the lameness assessment and clinical examination. The samples were transferred to and stored at refrigerator temperature until processed the next day. The serum samples were stored after centrifugation at 18°C until analyzed. The haptoglobin concentration was determined by using the bovine hemoglobin-binding assay (Makimura & Suzuki, 1982), with slight modifications for pigs as described by Heinonen et al. (2010).

Treatment and definition of treatment success (Studies II and III)

Lame sows were allocated randomly to one of the following treatment groups: (1) ketoprofen 4 mg/kg, (2) ketoprofen 2 mg/kg, (3) placebo. Ketovet vet 2.4 g oral powder (Provivo) was used as the test product for the 4 mg/kg dose and a mixture of Ketovet vet 2.4 g oral powder and placebo in a 1:1 ratio for the 2 mg/kg dose. The placebo contained 14 g of maltodextrine and 1 g of carmellose sodium.

The correct daily dose was calculated on the basis of each animal's body weight. The bodyweight (kg) of the animals was calculated using the following formula: circumference^2 (cm) x length

(cm)/13781 (Savage, 2004). Before administration, the powder was mixed with tap water and drawn into a 20 ml syringe. To give the medication, the owner went next to the sow, placed the tip of the syringe through the corner of the mouth deep into the mouth of the sow and dispensed the liquid directly onto the base of the tongue. The medication was given once a day for five days (days 1–5), starting from the day after the enrollment into study.

The treatment was considered successful if the lameness score on Day 5 was 0 or 1 (Study II). A lameness score of 0 was regarded as an excellent efficacy, and score 1 as a good efficacy. A decrease of lameness score from 4 to 2–3 or from 3 to 2 was regarded as a fair efficacy. No change in lameness indicated a poor efficacy of the treatment. In Study III, lameness was regarded as relieved if treatment was considered successful.

Behavior observation (Study III)

Two persons blind to the lameness and treatment status of the sows monitored their behavior using a scan-sampling method with 5-minute intervals for 2 hours, providing 24 observations per sow per day. The scan-samplings were done twice: before treatment on Day 0 and after the fifth treatment on Day 5, starting 10 min after afternoon feeding (see Figure 1). An ethogram modified from Munsterhjelm et al. (2008) was used in evaluation of the behavior of the sows (Table 5). The sows were marked with animal spray on their backs to enable individual identification. The observers were positioned in the alley between the pens and before the start of the observation they walked three times through the alley to let the sows get used to them.

4.3 HOUSING OF SOWS (STUDY III)

Study sows were housed in nine 30 m^2 pens with solid walls. Each pen housed 9–11 sows. Two thirds of the pen floor were solid concrete, covered with 0.5–1 cm layer of chopped straw, and one-third of the floor was concrete slats. Sows were fed with a commercial dry sow feed twice daily. Sows were fed from a trough, divided by short walls into individual feeding places of 50 cm per sow. Water was freely available from one cup per pen.

4.4 STATISTICS

Statistical analyses were performed using SAS software (SAS Institute, version 8.2) in Study II and SPSS software in studies III and I (IBM SPSS Statistics for Macintosh, version 21.0; IBM Corp., Armonk, NY, USA, and for Windows version 24.0; IBM Corp., Armonk, NY, USA). In all studies, a P-value < 0.05 was considered statistically significant.

4.4.1 STUDY I

The differences in parity (continuous, normally distributed variable) between spontaneously dead and euthanized sows were analyzed with the t-test. Differences in frequencies of animals with clinical signs were analyzed using the Chi-squared test.

4.4.2 STUDY II

The treatment groups were compared using a Cochran-Mantel-Haenszel (CMH) test with respect to the lameness score on Day 0 and treatment success. Treatment successes stratified by farm, parity and lameness score on Day 0 were also compared. ANOVA (analysis of variance) was used to compare haptoglobin concentrations (data were normally distributed) in treatment groups and control animals.

4.4.3 STUDY III

Behavioral data were analyzed as number of observations per behavior. As no difference was detected between the efficacy of ketoprofen doses 2 mg/kg and 4 mg/kg in Study II, results for the two doses were pooled. Data were analyzed using non-parametric Mann-Whitney U and Kruskal-Wallis tests.

Table 5. The ethogram (modified from Munsterhjelm et al., 2008) used for scoring sow behavior in a study investigating the association between behavior and lameness (Study III). During the observation, a sow's position in the pen was recorded first, then her posture and thirdly the type of activity. Positions (except "in contact with the wall"), postures and activities formed three mutually exclusive behavior categories.

Behavior	**Description**
Position in the pen	
On the solid floor	Defined as where at least 50% of the animal is positioned.
On the feeding area	
On the slatted floor	
In contact with the wall	Some part of the animal is touching wall. Sows could be in contact with the wall in all pen positions listed above.
Posture	
Lying	Lying down on the sternum or on one side
Standing	An upright position on extended legs without moving
Sitting	The tail and posterior part of the body in contact and supported by the ground and the forelegs extended under the body
Moving	Walking or running across the pen, jumping, frisking
Activity	
Eating	Head in the feeder or chewing feed (not bedding)
Drinking	Use of water cup for drinking
Exploring substrate	Nosing, sniffing, touching, licking, chewing, sucking or rooting beddings
Exploring the pen	Nosing, sniffing, touching, licking, chewing, sucking or rooting any part of the pen or floor
Nosing/being nosed	Sniffing or touching any body part of other sow with the snout, no attempt to push/ Being the recipient of nosing
Walking	Moving forward without simultaneously doing any of the above listed activities
Passive	Performing no activity (sleeping, watching etc.)

5. RESULTS

The main results from the studies (I–III) are presented in this chapter. More details can be found in the original articles included at the end of the thesis.

5.1 STUDY I

5.1.1 PATHOLOGICAL FINDINGS IN THE LOCOMOTOR SYSTEM

The locomotor system was the body part most commonly affected by lesions in this study, with 91% (n=60) of the animals affected. The most common PAD-1 was inflammatory arthritis, which was present in six sows (9%). The type and distribution of findings in the locomotor system are detailed in Figure 2. Primary and secondary PADs in the locomotor system categorized according to the means of death are presented in Table 6.

Degenerative joint disease was diagnosed in 46 animals (71%), when counting PAD-1s, PAD-2s and incidental findings together. The elbow joint was most commonly affected (n=32), followed by the shoulder (n=24) and knee (n=22). Degenerative joint disease was bilateral in two-thirds of the cases. Both front and rear leg were affected in 21 sows. Sixty-three percent (n=41) of sows had degenerative joint disease as an incidental finding.

5.1.2 OTHER FINDINGS IN POST-MORTEM EXAMINATION AND CLINICAL SIGNS BEFORE DEATH

From PAD-1s not related to the locomotor system, peritonitis was the most prevalent finding (9%), followed by abscess, pneumonia/pleuritic/bronchopneumonia and cardiogenic reasons, all of which were present in 5% of the sows. Categories of all PAD-1s and PAD-2s are presented in Table 7. Figure 3 presents PAD-1 categories for different parities.

Incidental findings were reported in all but one sow. Most sows had more than one type of lesion or a lesion in more than one location. Together with degenerative joint disease, tooth wear (71%), periodontal disease (26%), decubital ulcers (35%) and other skin lesions (45%) were the most prevalent findings.

Lameness (n=21), inability to stand up without assistance (n=17) and inappetence (n=17) were the most commonly reported clinical signs observed by the farmer within 30 days preceding death. Thirty sows (46%) were either lame or unable to stand up without assistance. Lameness was reported in 16 of 19 animals (84%) with a PAD-1 affecting the locomotor system. Of the sows having a decubital ulcer, eight (35%) of 23 were reported to be lame and 14 (61%) were reported to be either lame or unable to stand up without assistance.

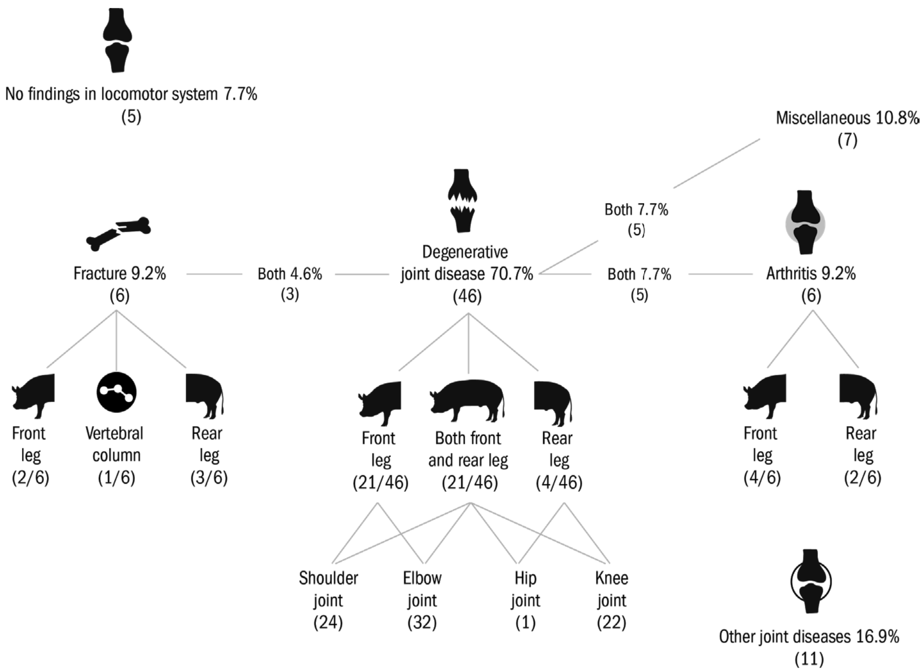

Figure 2. Findings in the locomotor system in post-mortem examination of sows found dead or euthanized in Study I, given as a proportion (%) of all sows in the data, and the number of sows (in parentheses). n=65.

Table 6. Primary and secondary pathological-anatomical diagnoses (PAD-1 and PAD-2) in the locomotor system in post-mortem examination of sows found dead (n=27) or euthanized (n=38) from 15 Finnish sow herds (Study I).

	PAD-1			PAD-2		
Pathological-anatomical diagnosis	**% of all sows**	**Found dead, n**	**Euthanized, n**	**% of all sows**	**Found dead, n**	**Euthanized, n**
Arthritis	9.2	0	6	0	0	0
Fracture	7.7	1	4	1.5	0	1
Osteomyelitis, vertebral column	3.1	0	2	0	0	0
Myositis or cellulitis	3.1	0	2	0	0	0
Digital dermatitis	1.5	0	1	0	0	0
Callus in the hoof	1.5	0	1	0	0	0
Degenerative joint disease	1.5	0	1	6.2	0	4
Myositis due to trauma	1.5	0	1	0	0	0
Periarthritis	0	0	0	1.5	0	1

Table 7. Categories of primary and secondary pathological-anatomical diagnoses (PAD-1 and PAD-2) in post-mortem examination of sows found dead (n=27) or euthanized (n=38) from 15 Finnish sow herds (Study I).

	PAD-1			PAD-2		
PAD category	**% of all sows**	**Found dead, n**	**Euthanized, n**	**% of all sows**	**Found dead, n**	**Euthanized, n**
Locomotor, inflammatory[1]	16.9	0	11	1.5	0	1
Locomotor, non-inflammatory[2]	12.3	1	7	7.7	0	5
Inflammatory, other than locomotor[3]	30.8	11	9	9.2	3	3
Cardiogenic	4.6	2	1	0	0	0
Miscellaneous[4]	12.3	3	5	12.3	5	3
Unknown, suspected cardiogenic	9.2	6	0	0	0	0
Unknown	13.8	4	5	0	0	0

The sows in the category had following diagnoses:

[1] arthritis, osteomyelitis, myositis, cellulitis, digital dermatitis, periarthritis

[2] fracture, callus in the hoof, degenerative joint disease, myositis due to trauma

[3] peritonitis, pneumonia, pleuritis, bronchopneumonia, generalized infection, infections of uterus, cystitis, enteritis, pericarditis, septic shock

[4] decubital ulcer, torsion of abdominal organ, spleen rupture, rectal/vaginal/uterine prolapse, anemia, hypovolemic shock, gastric ulcer

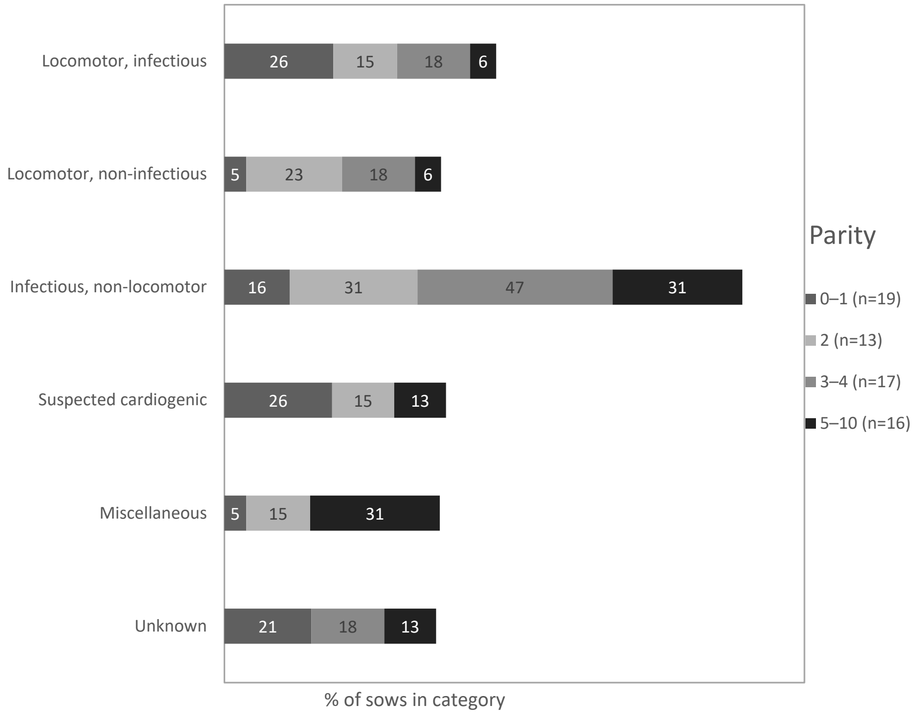

Figure 3. Categories of primary pathological-anatomical diagnosis (PAD-1) of dead and euthanized sows (n=65) in different parities in Study I.

5.2 EFFECT OF ORAL KETOPROFEN IN TREATMENT OF NON-INFECTIOUS LAMENESS (STUDY II)

The treatment was considered successful for 54% of the animals in the ketoprofen 4 mg/kg group, 53% of the animals in the ketoprofen 2 mg/kg group and 21% of the animals in the placebo group.

The efficacy of treatment in different groups is presented in Table 8. The difference between the ketoprofen groups and the placebo group was significant (P=0.001, CMH test stratified by farm), but there was no difference between the two ketoprofen groups (P=0.78).

Table 8. Efficacy of treatment of lame sows in three treatment groups: ketoprofen 4 mg/kg, 2 mg/kg and placebo, administered orally for 5 days. n=141.

Efficacy	Ketoprofen 4 mg/kg, number (%) of animals	Ketoprofen 2 mg/kg, number (%) of animals	Placebo, number (%) of animals
Excellent	7 (15%)	10 (21%)	2 (4%)
Good	18 (39%)	15 (32%)	8 (17%)
Fair	4 (9%)	8 (17%)	10 (21%)
Poor	17 (37%)	14 (30%)	28 (58%)

Mean values for haptoglobin concentrations (mg/L) in ketoprofen 4 mg/kg, ketoprofen 2 mg/kg, placebo and control groups during the first sampling (Day 0) were 1910, 1797, 1833 and 1878 and during the second sampling (Day 5) 1702, 1838, 1802 and 1825, respectively. No significant differences were detected between the groups. No sows were excluded retrospectively from the study because of haptoglobin values.

5.3 BEHAVIOR CHANGES ASSOCIATED WITH LAMENESS (STUDY III)

Lame sows were observed to be more passive, to lie down more and stand and explore pen fixtures less than the healthy control sows on Day 0. The differences between the behavior of lame and healthy control sows on Day 0 are presented in Figure 4.

Lameness was relieved in seven out of 13 sows on Day 5: in six of nine (67%) ketoprofen-medicated sows and in one of four (25%) placebo-treated sows. On Day 5, sows with non-relieved lameness were in contact with the wall and lying down more than healthy control sows. In addition, they were moving and standing less than healthy control sows. The effect of lameness relief on behavior of sows is shown in Figure 5.

The effects of treatments on behavior of sows are shown in Figure 6. When comparing the treatment groups, ketoprofen-treated sows were observed to be less in contact with the pen wall and exploring bedding more than placebo-treated sows. In addition, ketoprofen-treated sows were lying down more and standing less than healthy control sows. In comparison with healthy control sows, placebo-treated sows were observed to be in contact with the wall and to lie down more.

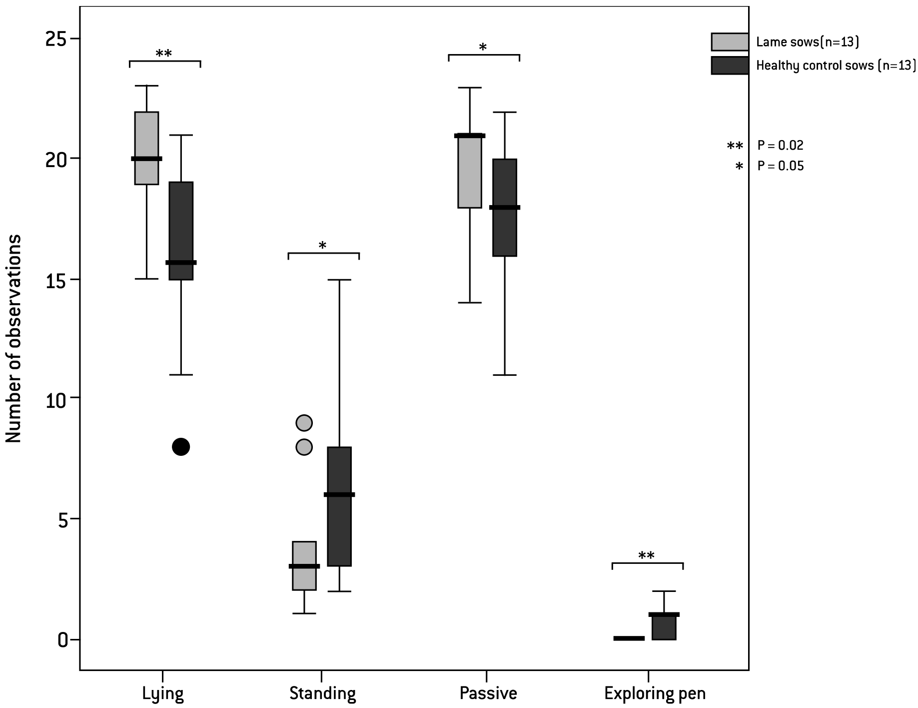

Figure 4. The behavior of lame and healthy control sows at the beginning of the Study III (Day 0). Only behaviors that differed statistically significantly ($P \leq 0.05$) between lame and control sows are presented. Sow behavior was recorded every 5 minutes for 2 hours by direct observation. Numbers of observations are given as median, lower and upper quartiles and range. Dots represent outliers.

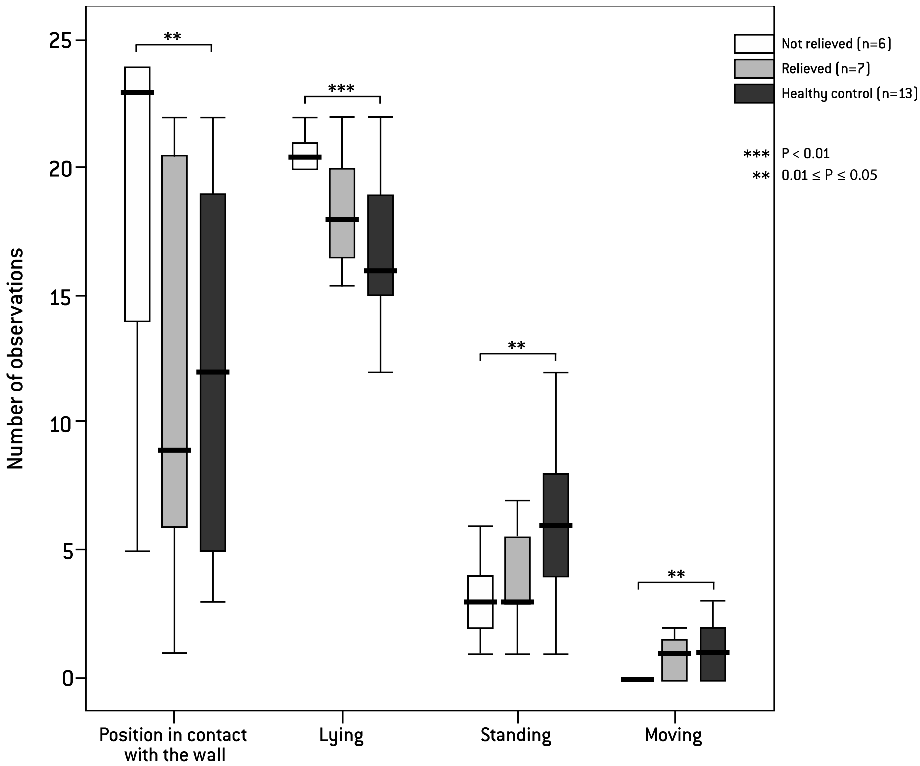

Figure 5. The effect of relief of lameness on the behavior of sows after the 5-day treatment (ketoprofen 2 or 4 mg/kg or placebo) in Study III. Only behaviors that differed statistically significantly ($P \leq 0.05$) between the groups are presented. The behavior was recorded every 5 minutes for 2 hours by direct observation. Numbers of observations are given as median, lower and upper quartiles and range.

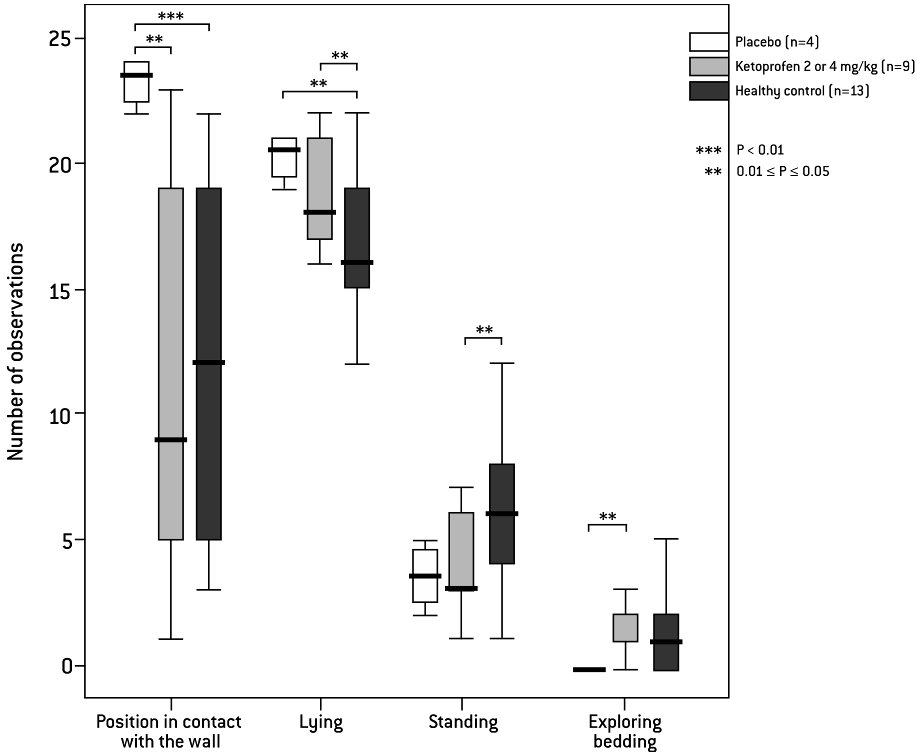

Figure 6. The effect of treatment (oral ketoprofen 2 or 4 mg/kg or placebo) on the behavior of sows after the 5-day treatment in Study III. Only behaviors that differed statistically significantly ($P \leq 0.05$) between the groups are presented. The behavior was recorded every 5 minutes for 2 hours by direct observation. Numbers of observations are given as median, lower and upper quartiles and range.

6. DISCUSSION

This study demonstrated that the pathological-anatomical findings in the locomotor system are common in OFD sows. The high number of findings in the locomotor system was actually surprising. They were also an important reason for euthanasia of sows, but only rarely a cause of spontaneous death. The findings in the locomotor system were mostly non-infectious by nature. Moreover, the non-infectious lameness of sows was successively alleviated with administration of an analgesic drug, as oral ketoprofen proved to be an effective treatment for lame sows. In addition, behavior observation revealed differences between behavior of lame and healthy sows. The results together highlighted especially the significance of the non-infectious causes of sow lameness.

Part of the results may be applied as such. The efficacy of oral ketoprofen in treatment of lameness is an example of research results, which are readily usable. From the animal welfare point of view, it is beneficial to alleviate the pain of lame sows. Also, the information concerning the behavior of lame sows can be used in finding and diagnosing lame animals in group: the animals lying close to the wall passively and not exploring the pen should be checked more carefully, as these animals are more likely to be lame. Many farmers and veterinarians have probably already used this kind of signs in practice, although without scientific proof of their usefulness. However, not all of the results were so easily interpreted. More than answers, some of the results stimulated new research questions. What does it mean if most of dead sows had pathological findings in the locomotor system? To what extent does it apply to living sows also?

The main results of the thesis will be discussed in this chapter, contrasting them with existing knowledge. Some proposals for future research will also be given.

6.1 PATHOLOGICAL FINDINGS IN THE LOCOMOTOR SYSTEM (STUDY I)

The vast majority (91%) of sows had different pathological findings in their locomotor system, making this body part most commonly affected by lesions in the present study. The PAD-1 was associated with locomotor system in 29% of sows. All locomotor system associated PAD-1s except one were found from euthanized sows. These results confirm the research findings in earlier papers by Kirk et al. (2005) and Engblom et al. (2008): problems in the locomotor system do not cause spontaneous deaths of sows, but they are an important underlying reason for euthanasia. Inflammatory arthritis was the most common PAD-1 in both present and earlier studies (Kirk et al., 2005; Sanz et al., 2007; Engblom et al., 2008), where the prevalence ranged from 17% to 36%. The definition of arthritis was quite similar in all of these studies as the joints of the sows needed to have cloudy or purulent synovial fluid. The prevalence was lower in the present study (9%), which may be due to differences in pen surroundings or other risk factors. None of the studies described management factors of the farms, so the reasons for differences between prevalence levels remain speculative.

The definitions of osteochondrosis, arthrosis and degenerative joint disease (DJD) have not been consistent in earlier studies, which limits the possibility to compare results. The presence of gross lesions, meaning at least erosion or thinning in joint surfaces was regarded as DJD in the present study, and with this definition, DJD was found from 71% of the sows in total. As 17% of sows had other joint lesions, it can be calculated that the prevalence of joint lesions was altogether nearly 100%. The primary causes of the DJD-cases were most likely osteochondrosis. The etiology was suggested by bilateral presentation and high prevalence (Ytrehus et al., 2007; Etterlin et al., 2017). Similar trends in prevalence of DJD and corresponding lesions, i.e. osteochondrosis and arthrosis, can be seen in other studies also (see Table 1). It seems that DJD is seldom a PAD-1 of a sow, but joint lesions as an incidental finding are very common. For example, very similarly to present results, Kirk et al. (2005) reported arthrosis as a secondary diagnosis in 88% of sows. As an exception to that, Dewey et al. (1993) reported up to 34% of sows having osteochondrosis as a PAD-1. However, the sampling of Dewey et al. (1993) differed from other studies, as all the examinations were performed on lame sows.

6.2 MULTITUDE OF PATHOLOGICAL FINDINGS (STUDY I)

Several pathological findings per sow were the norm in this stud. This raises concern about the health and welfare of sows in general, although, the study sows do not represent the population of sows in production in the farms. It was expected that OFD sows have pathological findings and the study design may have led to an overrepresentation of complicated cases. Still, the large number of different pathological findings was surprising. The existing literature does not provide much information about this and lack of detail in description of the methods further complicates comparisons. Engblom et al. (2008) listed numerous incidental findings, but did not report the proportion of sows having several pathologies. Sanz et al. (2007) reported that 57% of 107 sows from one herd had at least two types of lesion. Nonetheless, multiple pathologies may indicate that the course of illness was prolonged and treatment and/or euthanasia delayed, which is a potential risk for animal welfare.

6.3 PRIMARY PATHOLOGICAL-ANATOMICAL DIAGNOSIS IN RELATION TO PARITY

When looking at PAD-1s according to parity, locomotor diagnoses clearly clustered to young sows (parity 0–4). Despite the multitude of lesions in the locomotor system in all, those were only infrequently a primary reason for death from parity 4 onwards. This is well in accordance with other reports. Lameness and locomotor problems are the reason for removals, especially of young sows (Engblom et al., 2007 & 2008; Pluym et al., 2013a). One explanation for this is that parities 2–3 may be the age at which a sow with congenital disorders (such as osteochondrosis) or other weaknesses in the locomotor system manages in the production environment of a modern piggery.

6.4 LAMENESS IN RELATION TO PATHOLOGICAL FINDINGS (STUDY I)

In the present study, 32% of the sows were reported to be lame $\leq$ 30 days before death. Lameness appeared to predict the category of PAD-1 well, as 84% of lame sows had the PAD-1 in the locomotor system. On the other hand, most of the sows having DJD were not reported to be lame. Clinical signs before OFD, including lameness, were observed and reported to the researchers by farmers. Lameness is said to be relatively easily identified by farmers (Jensen et al., 2010), but it is often uncertain whether it is identified accurately. A veterinarian might have identified more sows as being lame, but it was impossible to organize a veterinarian to do an ante-mortem examination for every sow in this study. Either way, the connection between lameness and degenerative joint lesions is not straightforward, as reported in several studies (Ryan et al., 2010; de Koning et al., 2015; Etterlin et al., 2015; Bertholle et al., 2016). As a consequence of this, the clinical relevance of DJD and corresponding lesions in sows remains unclear. The considerably high number of these lesions sets anyway targets for future research. It would be important to clarify clinical signs associated with degenerative joint lesions and their significance to sows, have longer follow-up periods and more detailed lameness assessments than in the present study.

Decubital ulcer was a common incidental finding in this study. Decubital ulcers are assumed to be painful, but scientific evidence of this has not yet been established (Herskin et al., 2011), and also, the association between decubital ulcers and lameness has remained undetermined so far (Rioja-Lang et al., 2018; Herskin et al., 2011). The results of the present study give hardly any new evidence about this association, although when looking not only lameness but locomotor signs more widely, 61% of the sows having decubital ulcer were either lame or unable to stand up without assistance before death. However, the sows had several other pathological findings also, which may have produced the clinical signs observed.

6.5 EFFECT OF ORAL KETOPROFEN IN TREATMENT OF LAMENESS (STUDY II)

The study demonstrated that oral ketoprofen was efficient in the treatment of non-infectious lameness of sows in a little more than half of the cases. No difference was found between the efficacy of the two ketoprofen doses and the efficacy was similar to the efficacy of injectable meloxicam (Friton et al., 2003). At the beginning of the study, some owners were skeptical about the oral administration of the drug for the loose-housed sows, but it proved to be easy. Furthermore, no adverse effects were detected. These findings support the use of oral ketoprofen as an analgesic for sows. As the smaller dose is cheaper, easier to administer and may cause smaller risk for adverse reactions, the findings of this study also support using the smallest effective dose of oral ketoprofen, i.e. 2 mg/kg. Although studies suggest that the bioavailability of both oral ketoprofen and oral meloxicam are good and they are well absorbed in pigs (Mustonen et al., 2012; Pairis-Garcia et al., 2015c), the advantages of oral analgesics have not been discussed widely. Other studies about the efficacy of NSAIDs in treatment of sow lameness have tested mostly injectable products and only single dose (Pairis-Garcia et al., 2015a; Conte et al., 2015). Even the most recent report about the use of NSAIDs in pigs (Schoos et al., 2019) skipped the comparison of different administration routes. Besides effectiveness, other characteristics and advantages of selectable drugs should also be considered: accessibility, local official approvals in each country, cost-effectiveness, meat withdrawal period, easy administration and the absence of potential injection site lesion in oral drugs (Pairis-Garcia et al., 2015b). Furthermore, pain and potential hygiene risks associated with injections can be avoided with oral drugs. From the animal point of view, oral solutions are a good alternative to injectable drugs. This is valid especially when NSAID treatment is required for several days, which often applies to lameness.

In this study (II), ketoprofen was given for five days, which is longer than the approved duration of oral ketoprofen (Veterinary Medicines Directorate, 2018). Even then, no clinical signs of adverse reactions were noticed. Earlier, ulcers and lesions of gastric mucosa have been the most presumable adverse effects (Rainsford et al., 2003). In the present study, the sows continued in production i.e. they were not culled after the study period, so the pathology of their gastric mucosa was not investigated. It is notable that only a few gastric ulcers were found in the pathological examinations of Study I. This may be due to preventive actions, like roughage provision and adequate grain particle size, which are commonly carried out on Finnish farms.

The ketoprofen-treatment was not successful in 46% of the lame sows, i.e. the lameness was not relieved (Study II). It could be interpreted that ketoprofen was not effective in treating pain in those cases or the duration of treatment was not long enough. The sows were followed only the study period, 5 days, leaving future events of the sows unclear. It is also possible that lameness was not due to pain initially. The causes of lameness were limited to non-infectious cases, but still the lameness could have arisen from various sources. The effect of ketoprofen may have been different depending on the cause of lameness. More detailed diagnoses are needed in further studies to define more specifically, in what kind of lameness cases ketoprofen-treatment is effective. The lack of effect also reminds that in the clinical practice the curative effect of any chosen treatment for a lame sow should be carefully monitored. The efficacy of treatment is particularly uncertain, when the treatment is chosen symptomatically without an exact diagnosis.

On the other hand, lameness was relieved in 21% of the placebo-treated sows. A similar effect was reported by Friton et al. (2003). Placebo effect is a well-recognized phenomenon in humans, and analgesia is particularly susceptible to placebo responses. The area is not widely studied, but also animals seem to express placebo-induced analgesia (Nolan et al., 2012). Of course, some of the lameness cases may have recovered spontaneously.

6.6 NON-INFECTIOUS CAUSES OF LAMENESS (STUDIES I–III)

A considerable portion (42% of PAD-1s) of diagnoses in the locomotor system was non-inflammatory in Study I. The term “inflammatory” was used instead of “infectious” in Study I to be more accurate and to clarify the categorization of PADs. In Studies II–III, the exact cause of lameness was not determined, but rather extensive measures were employed to exclude infectious causes out (see section 4.2.3 about Inclusion criteria). The reason to include only non-infectious cases in the study was the aim that analgesia would have been the only medication the lame sows were in need of. Based on the results of Study I, it can be concluded that the diagnoses causing lameness in Study II could have been e.g. DJD or myositis. Finally, only a few lame sows were excluded from the study (II–III) because of them having an indication of ongoing infection and simultaneously, an indication for antimicrobial-treatment. Moreover, no sows were excluded because of the haptoglobin values, which were determined to ensure the exclusion of subclinical infectious cases retrospectively. Mean haptoglobin values of the study sows were in accordance with the reference mean value 1.47 mg/mL reported by Piñeiro et al. (2009).

The lameness of sows in Study I was not determined using a validated method, and it is not correct to assume that lameness and lesions in the locomotor system are synonymous. However, based on findings of Study I it is entitled to assume that lameness of sows is often caused by non-inflammatory reasons, and this kind of lameness can be successfully treated with ketoprofen (Study II). The findings of the Studies I and II together provide new evidence of the significance of non-infectious causes of sow lameness. This evidence supports increased use of NSAIDs in medical treatment of sow lameness, and also, decreased need to use antimicrobials.

6.7 BEHAVIOR CHANGES ASSOCIATED WITH LAMENESS (STUDY III)

Results of Study III supported the hypothesis and demonstrated that lame sows were more passive than healthy control sows. Lame sows were exploring the pen and standing less and lying more often than healthy sows. In addition, the effects of ketoprofen treatment and clinical relief of lameness on behavior of sows were established. After the clinical relief of lameness, the behavior of sows did not differ from that of the healthy ones.

Sickness behavior associated with infection is well documented. The most commonly recognized behavioral signs of animals encountering an infectious disease are lethargy, depression and anorexia (Hart, 1988). A fairly similar behavioral response was seen in connection with non-infectious lameness, as the results of Study III indicated. Other studies have also shown analogous results (Grégoire et al., 2013; Pairis-Garcia et al., 2015a). The reduced activity may be a sign of sickness in general, or it may be a sign of pain. In this study (III), giving analgesics to lame sows reduced the behavioral differences seen between lame and healthy control sows before treatment. This indicates that lame sows were in pain. Attempts to measure pain in animals objectively and scientifically are particularly challenging as pain is a subjective and personal experience (Ison et al., 2016). Considering lameness, it is especially difficult to distinguish whether the outcome, behavior in this case, is caused by pain. Behavior can also be caused by other features of lameness, like impaired mobility. Impaired mobility and pain are certainly equally relevant when assessing the overall welfare or suffering in relation to lameness (Ison et al., 2016). Even if it is impossible to determine whether lameness is associated with pain, the abnormal gait is likely to be associated with a cost to the animal, and can be taken as an indication of a reduction in quality of life (KilBride et al., 2009).

Observing lame sows with and without analgesia, as was done in Study III, is a validated method to assess pain, and allows separating the effects of pain from other effects of the condition (Weary et al., 2006; Ison et al., 2016). Ideally, the outcome would show a linear change dose-dependently with the use of an effective analgesic, and the outcome would be specific to pain. For example, the increased number of high-frequency calls produced by piglets during castration is a pain-specific behavior associated with acute pain (Taylor & Weary, 2000). In the present study, the sample size was too small for dose-dependent comparisons, and the behaviors that were chosen for the ethogram were general behaviors of sows, and not pain-specific. Additionally, the behaviors were long-term, and vocalization is such a short-term behavior that it could not be reliably measured using a 5-min scan-sampling, which was used in this study. Partly, the 5-min scan-sampling was chosen for practical reasons, but also because the lameness of sows was expected to be more chronic than acute. Moreover, chronic pain was expected to cause subtle and more long-term behavior changes, like inactivity, which could be detected using the chosen method. When looking at the results of Study III, it can be seen that despite the small sample size and rather short observation period, the behavioral differences between lame sows, sows with relieved lameness and healthy control sows were logical.

6.8 SPECIAL NEEDS OF LAME SOWS AND PREVENTION OF LAMENESS

At the group-level, ill and injured individuals represent a vulnerable population with unique needs and preferences. The fact that 46% of the sows were still lame after the 5-days course of medication (Study II) reflects that lame sows may need other kind of treatment besides analgesia. In Finland, the legislation about protection of pigs prescribes that at least 5% of the total pen area of the farm has to be reserved for sick and injured animals (Animal Welfare Act, 1996). The design of hospital pens is not defined more specifically. Often, hospital pens are just standard pens, where sick animals are separated or moved prior to euthanasia (Millman & Friendship in Millman, 2007).

The findings for behavior of sows with lameness (Study III) may be an important starting point when investigating the special needs of lame sows in relation to pen surroundings. As lame sows spend more time lying down, hospital pens should especially provide the possibility to lie comfortably. This could be facilitated e.g. by extra bedding or rubber mats (see chapter 2.4.2 Supportive care) The preference of sows with non-relieved lameness to stay in contact with the wall could be interpreted as a way of seeking shelter and isolation from the group. By lying next to the wall, a sow may have been protecting herself from pushing and attacks of other sows, and isolating herself from the group to save resources for the convalescence. Preferred pen location of animals in pain could be further evaluated by preference studies (Weary et al., 2006). To date, such studies have not been published about lame pigs.

As the old phrase goes, prevention is better than cure. Genetics, housing, flooring, group size and nutrition are factors, which may have an impact on the development of lameness (Pluym et al., 2013a; Maes et al., 2016). However, as long as we are dealing with lameness without determining the exact cause of it, it will be difficult to give specific preventive measures. Prevention of lameness necessitates knowing the diagnosis. This study did not investigate prevention of lameness. However, the findings are guiding future research towards the non-infectious causes of sow lameness.

6.9 STRENGTHS AND LIMITATIONS OF THE STUDY

The studies of this thesis were carried out in several commercial farms under real production conditions. From applicability point of view, this is a strength of the thesis. When findings and effects are consistent between farms, they are likely to be true and not caused by chance (Westin, 2014). However, collecting field data is often very time-consuming and laborious leading to small sample sizes (I and III) and it is not possible to collect all the data that scientists would like to have for their research, as happened in Study I.

The major weakness in Study I was that the farmers were able to choose which sows they sent for post-mortem examination, and this may have led to selection bias of sows. In other words, the most complicated and unusual cases may have ended up as study animals, while farmers may have chosen not to send the more common cases. This unavoidably impairs the generalizability of the results. The original aim of the study was to examine all dead and euthanized sows on ten farms during a year. Despite encouragement and financial support for farms, it proved to be very difficult to make the farmers to send the sows for post-mortem examinations. Probable reasons to this were that carcasses are troublesome to handle and move and distances in Finland are long. Farmers may have considered the extra work needed unprofitable. In addition, the sows were included in a study only if the post-mortem examination could be arranged on the day following the death at the latest. This was sometimes impossible, as for example during weekends the transportation of carcasses was difficult to organize. An additional limitation for Study I was that one farm was overrepresented in the sample. However, when looking at the PAD-1s, sows from this farm represented the whole sample well.

The special strength of Study II was that the efficacy of analgesia was evaluated on sows with naturally occurring lameness. In comparison with experimentally induced lameness, the naturally occurring lameness originates from much more multifactorial etiologies (Pairis-Garcia et al., 2015b). Therefore, the conditions of the present study are closer to everyday situations on sow farms, which improves applying the results in practice. However, naturally occurring cases are likely to cause pain associated with lameness to be more unpredictable, which increases the number of confounding factors.

It is actually valid for the whole of this thesis that as the studies were not conducted in validated experimental research settings, confounding factors may have complicated the interpretation of the results. As a consequence of small sample sizes (I and III) and convenience sampling (I) it is justified to assume that the generalizability of the results may not be good. However, all the results reflect the real situations in Finnish sow farms.

7. CONCLUSIONS

Based on the findings from studies included in this thesis, and the existing literature, the following conclusions can be made:

1) Pathological-anatomical findings in the locomotor system are very common in on-farm-dead sows. For euthanized sows, also the primary pathological-anatomical diagnosis is often in the locomotor system. For spontaneously dead sows, the cause of death is typically elsewhere in the body.

2) Degenerative joint lesions are very common in on-farm-dead sows. The prevalence and clinical relevance of those lesions in the general sow population needs to be elucidated.

3) Oral ketoprofen is effective in treatment of spontaneous, non-infectious lameness of sows, at a dose of 2 mg/kg. No adverse effects were observed within the treatment of five consecutive days.

4) Lameness affects behavior of sows. Lame sows are more passive than healthy sows, they stand and explore pen fixtures less and they prefer to lie and stay in contact with the pen wall more often than their healthy penmates.

5) The results about the effect of ketoprofen in treatment of lameness and the behavior effects of lameness (see points 3-4) should be considered when planning and improving the management and supportive care of lame sows.

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